DER-CAM
DOE FY15 2nd Quarterly Review

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DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

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Partners: Massachusetts Institute of Technology (MIT), EPRI, Metropolitan Washington Council of Governments, Brookhaven National Laboratory, Fort Hunter Liggett, TriTechnic, Microgrid Labs Inc., MIT Lincoln Laboratory, University of New Mexico, Public Service New Mexico, Universidad Pontificia Comillas – IIT, Xcogen Energy LLC, CSIRO, NEC

U.S. DEPARTMENT OF ENERGY

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Overview Collaborations with BNL/COG/EPRI and Technical Progress

	planned	status
BNL	provide DER-CAM training to BNL, including formatting , inputting data, running scenarios, analyzing and interpreting results, and understanding the technologies in DER-CAM	completed
	LBNL provides advanced training to BNL staff on DER-CAM code	completed
	LBNL shall develop a user manual for the DER-CAM	completed
COG	support COG on engineering / economic analysis of microgrid development options for the St. Elizabeth's campus in DC	formed collaboration with EPRI and support COG, ongoing
	support and guide efforts to collect and enter data, design of analysis and sensitivities, use of the model	provided data templates to ease the data collection, training videos
EPRI	transfer DER-CAM to EPRI to support utilities, governments, etc.	very successful (e.g. NYPrize)
	form collaboration with EPRI and improve DER-CAM based on user feedback	very successful (e.g. improved result section)
Techn. Progr.	technology transfer	exceeding expectations
	enable DER-CAM with "green field" vs. "brown field" optimization	completed
	enable DER-CAM with unbundled transmission and distribution tariffs to consider changed tariff structures	ongoing
	take lead on interface design (web-based)	very successful
	start with power flow capabilities	ongoing and accelerated progress

Major DER-CAM Accomplishments #1

Outreach and TechTransfer work in the 2nd quarter

delivered as planned, with accelerated outreach to industrial and commercial users; DER-CAM classes and feedback from DER-CAM users

- transferred DER-CAM to EPRI
  - EPRI uses DER-CAM for microgrid design with its utility partners
  - NYPrize proposal with communities and utilities
  - EPRI uses DER-CAM to support the Metropolitan Washington Council of Governments (COG) for the St. Elisabeth's Hospital complex
- trained BNL staff on DER-CAM for use with communities and utilities in NY state, full week DER-CAM class
- adopted by engineering forms as General Electric, the Burns Group
- IEEE 2030.7 WG on microgrid controller standards

Technical work performed in 2nd quarter of FY15

completed as planned, with accelerated progress

- released next version of web-based interface microgrid design tool
- accelerated progress on microgrid topology, power flow capabilities
- additional DER-CAM features (load data processing, results navigation, graphical reports), collaboration with EPRI and member utilities, EPRI provided very helpful input for improving the DER-CAM interface
- advanced CHP module and data, 60% completed

Major DER-CAM Accomplishments #2

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- General Electric (GE) uses DER-CAM for microgrid projects
- Burns Engineering and Construction is using DER-CAM for the Philadelphia Navy Yard microgrid project and receives ongoing DER-CAM support and training
- Industry Advisory Group: GE, EPRI, Microgrid Labs, BNL, and multiple users are providing feedback on DER-CAM
- DER-CAM classes – well subscribed
  - the May 4th class was oversubscribed (26 users) and follow up sessions have been provided on May 6th, May 8th, and May 10th
  - participants from Schneider Electric, the Burns Group, Duke Energy, ConEdision, Google, Clean Coalition

Major DER-CAM Accomplishments #3

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- ARUP, a facility engineering firm is evaluating DER-CAM for urban development projects
- completed a full conceptual microgrid design with DER-CAM for Fort Hunter Liggett
- customized DER-CAM versions developed for advanced users are offered
- completed a manual, 50 pages, includes a use case, which is available at https://building-microgrid.lbl.gov/sites/all/files/DER-CAM_User_Manual_v1_Rev2.pdf

Major DER-CAM Accomplishments #4

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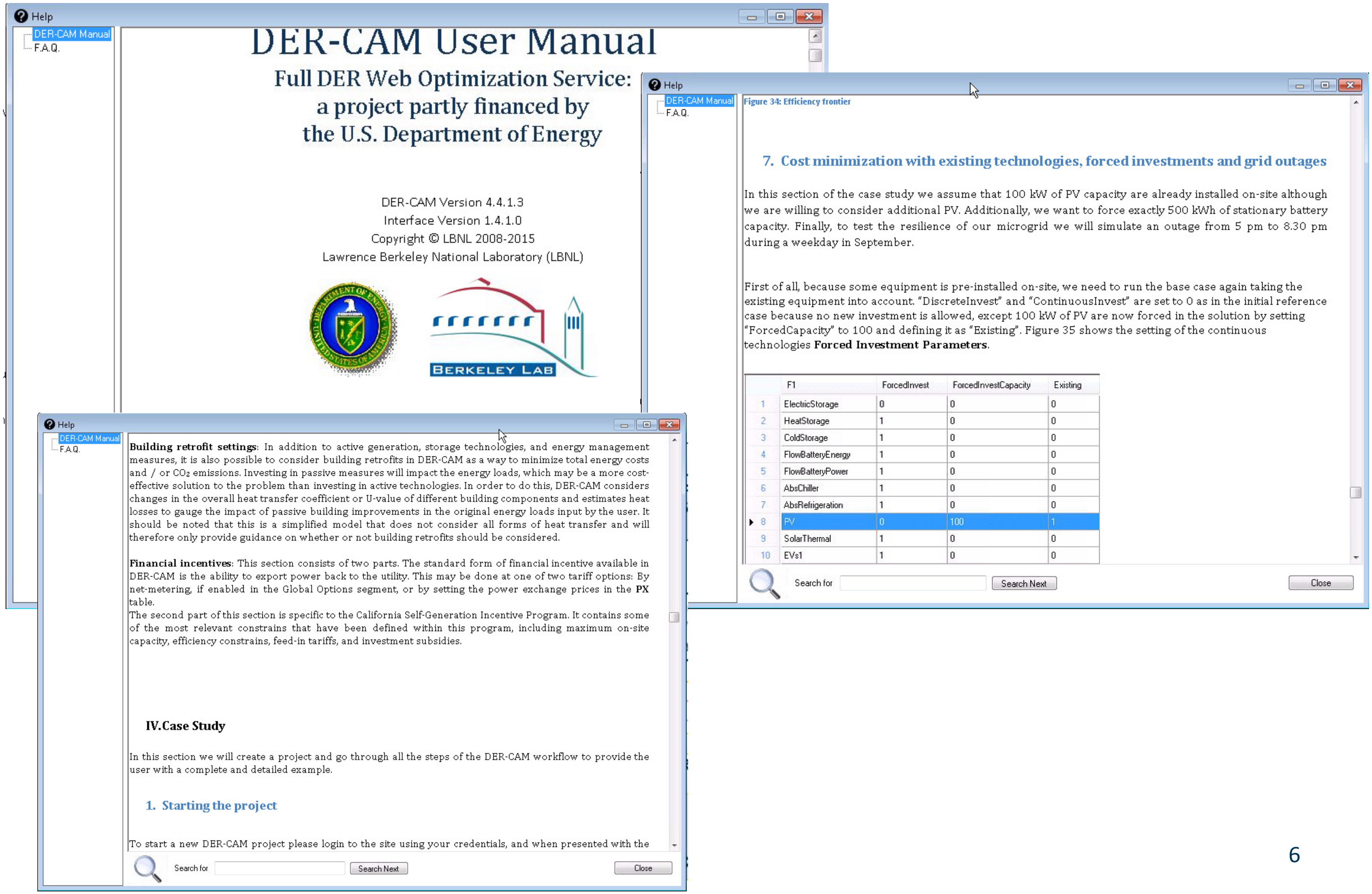
ANALYTICS | PLANNING | OPERATIONS



DER-CAM Partners

THE Burns GROUP
ENGINEERING AND CONSTRUCTION

EPRI ELECTRIC POWER RESEARCH INSTITUTE

xcogen ENERGY

BOSCH

U.S. AIR FORCE

BROOKHAVEN NATIONAL LABORATORY

MIT

THE UNIVERSITY of NEW MEXICO

UNIVERSITY OF CALIFORNIA SAN DIEGO

MIT Lincoln Laboratory

Our Partners

UNIVERSIDAD PONTIFICIA ICAI ICADE COMILLAS MADRID
The value of excellence

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

WASEDA UNIVERSITY

TÉCNICO LISBOA

MINES ParisTech

BACC Bay Area Climate Collaborative
Global Challenge. Regional Response

CSIRO

NEC

One-Cycle Control, Inc.
The Art of Power Processing

TRI-TECHNIC

Deusto
Universidad de Deusto
Deustuko Unibertsitatea
University of Deusto

LINKÖPINGS UNIVERSITET

UNI FREIBURG

TU WIEN ESEA
Institut für Energiesysteme und Elektrische Antriebe

IISM

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

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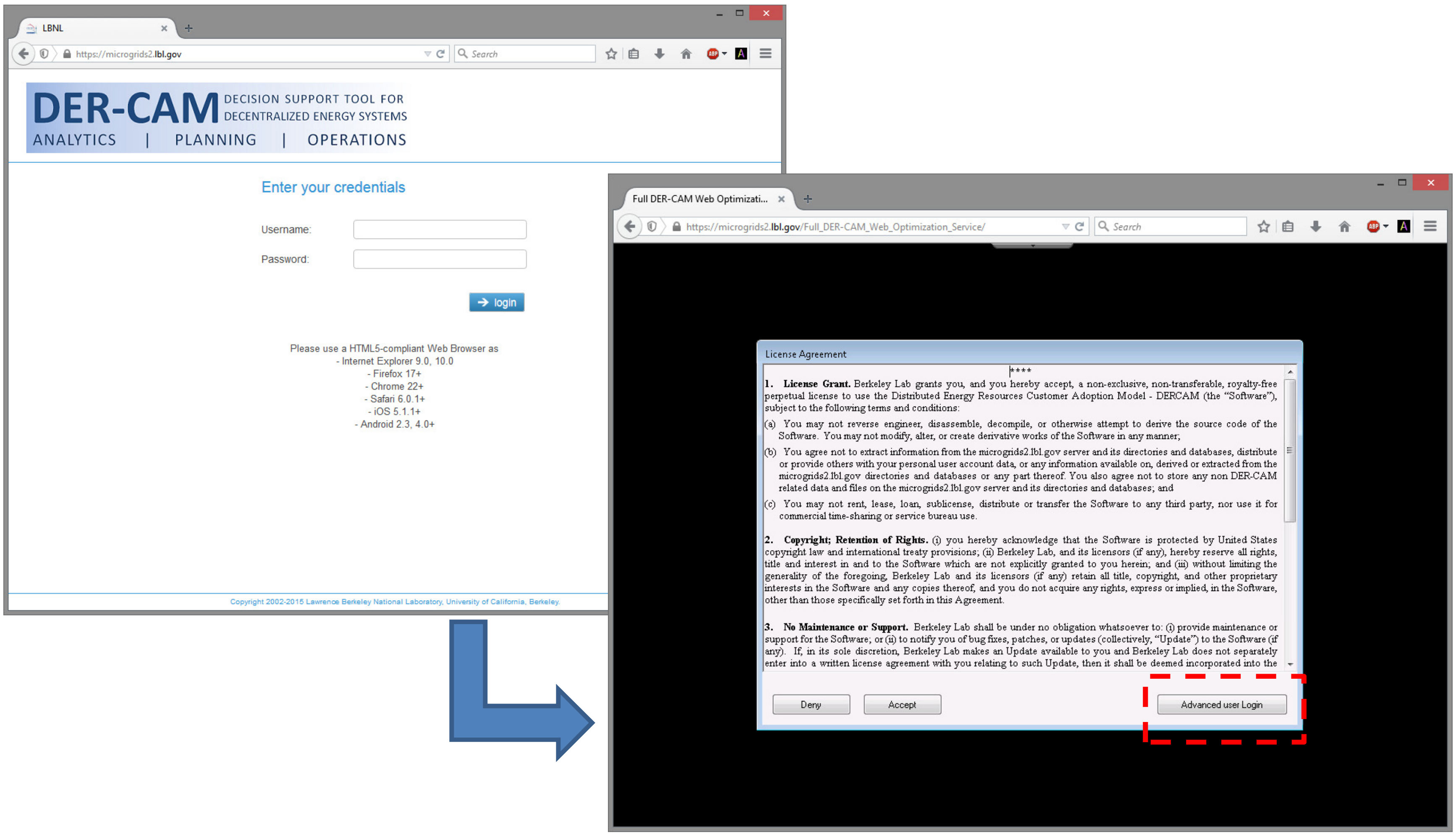
Excerpt of Technical Work Performed in 2nd quarter of FY15:

- ***web-based interface design and expanded DER-CAM's role as leading microgrid design tool***
- ***improved user Interface (load data processing, results navigation, graphical reports)***

Login Screen

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS

ANALYTICS | PLANNING | OPERATIONS



advanced user login allows access to customized versions

New Project

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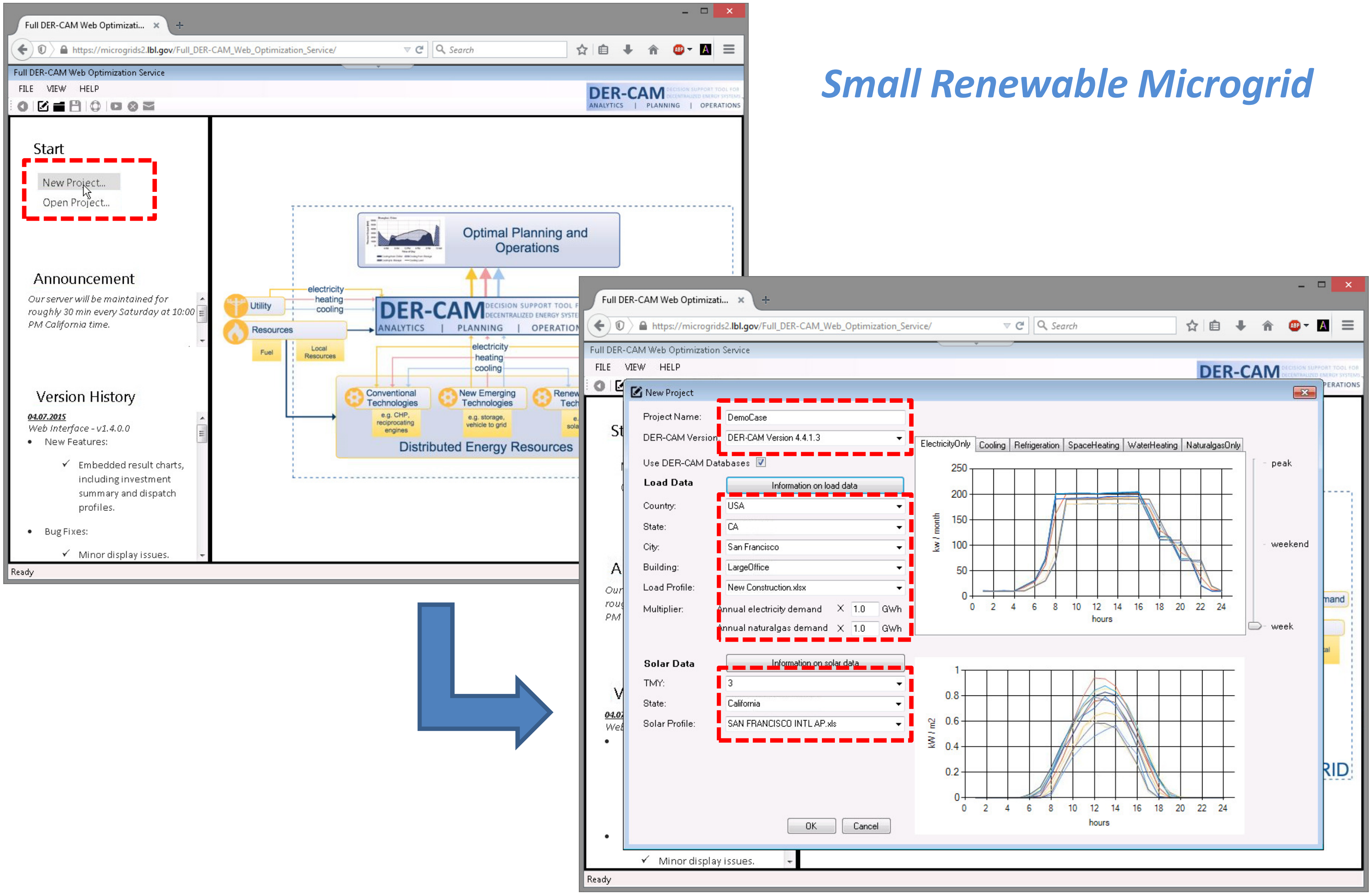
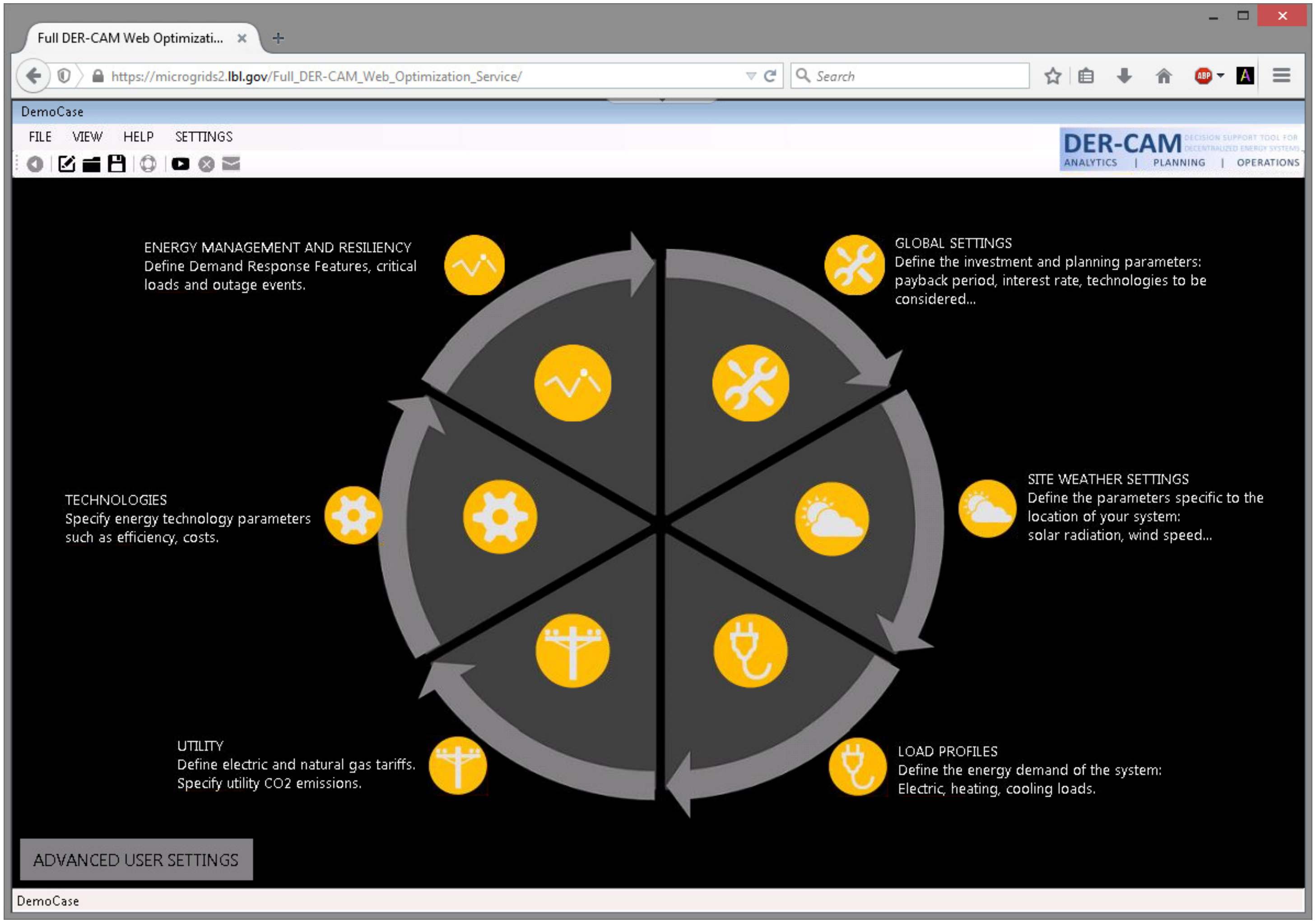
Small Renewable Microgrid



Model Overview

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS



Model Overview: Closer Look at the Utility Sub-Menu

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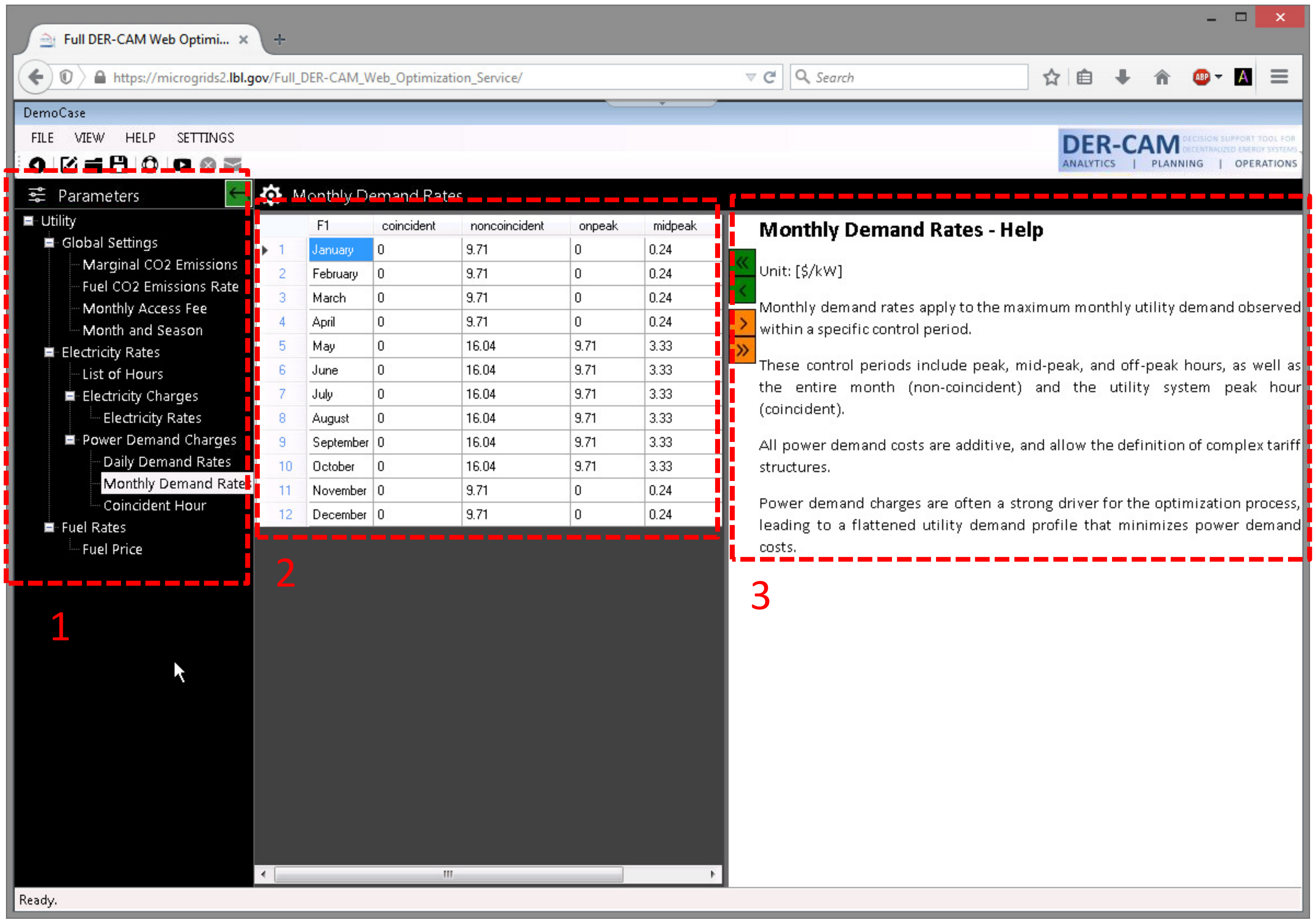
ANALYTICS | PLANNING | OPERATIONS



standard window structure: **1**: Table navigation ; **2**: Data input ; **3**: Help

Building a Model: Reference Case vs. Investment Case

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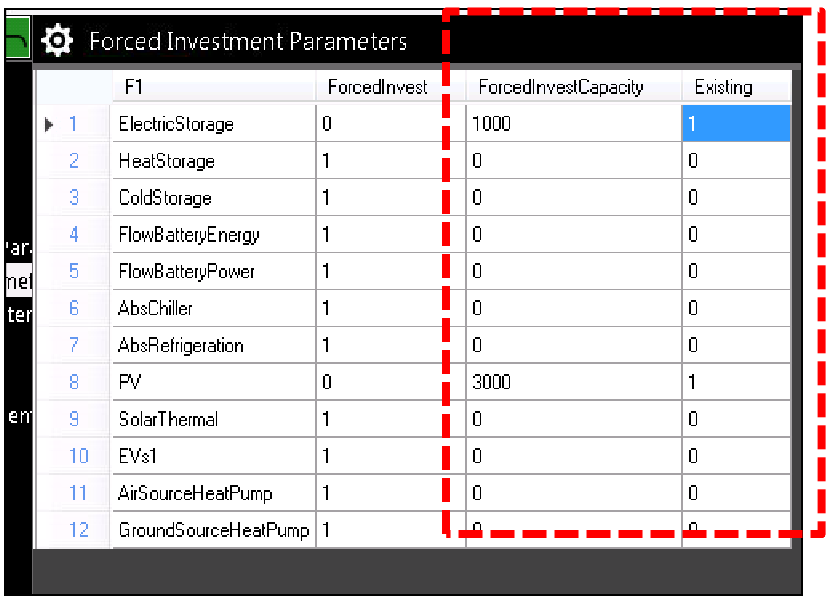
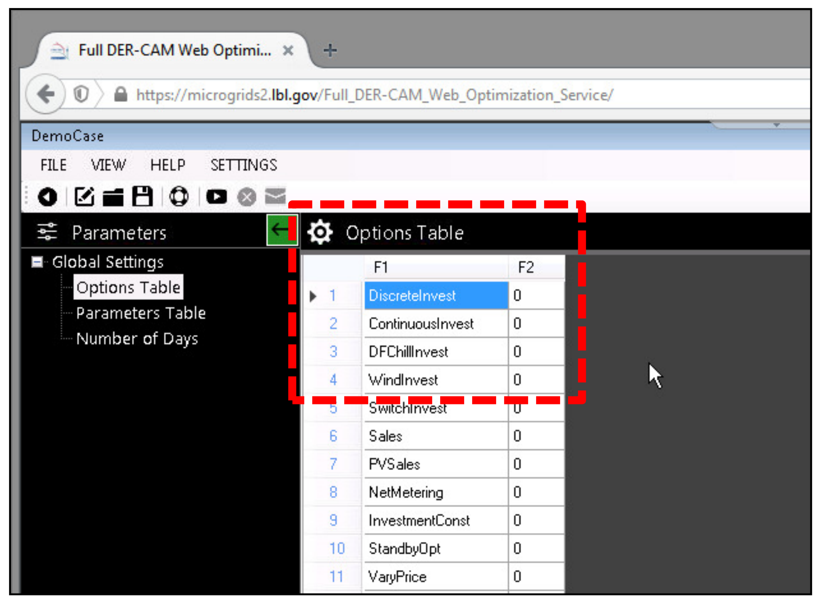
ANALYTICS | PLANNING | OPERATIONS

DER-CAM finds the optimal investment solution that satisfies several groups of constrains:

- energy balance (electric, heating, cooling, etc.)
- physical (rated capacity, conversion efficiency, available roof space, etc.)
- economic (discount rate, maximum payback period)

in order to satisfy the economic constrains, a **reference cost** must be obtained and the reference cost can be estimated by running DER-CAM with the existing infrastructure





Building a Model: Reference Case vs. Investment Case

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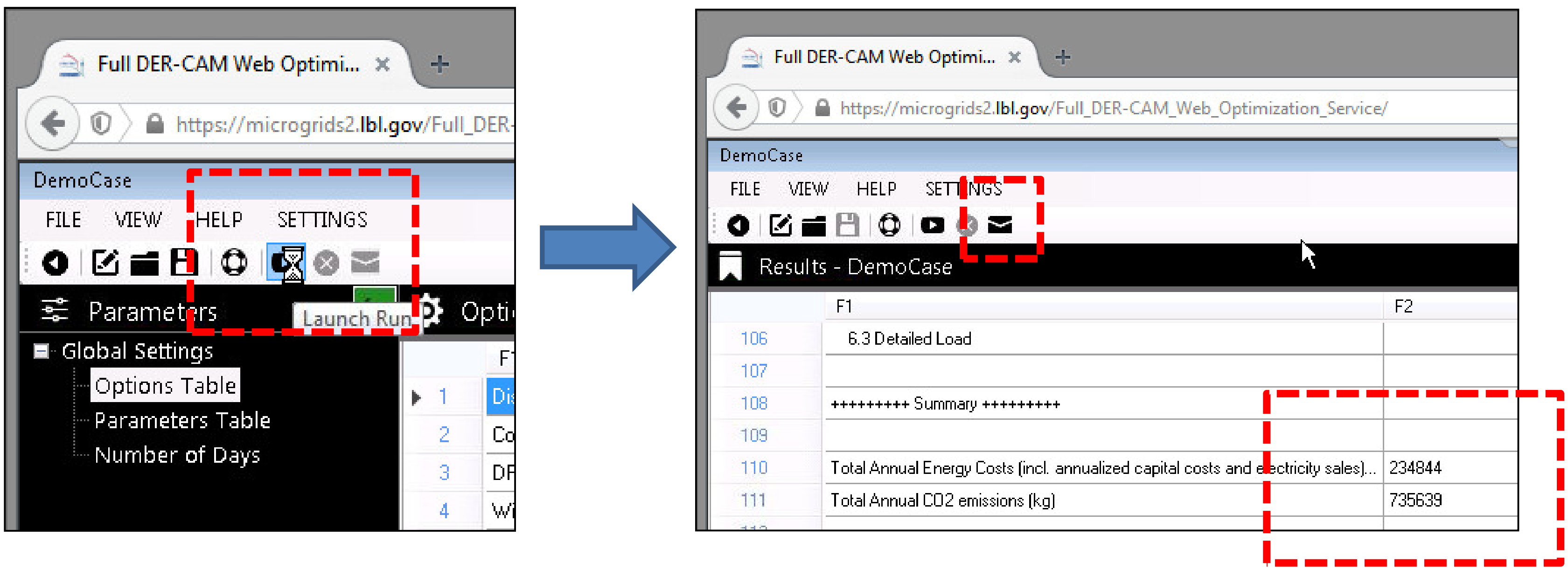
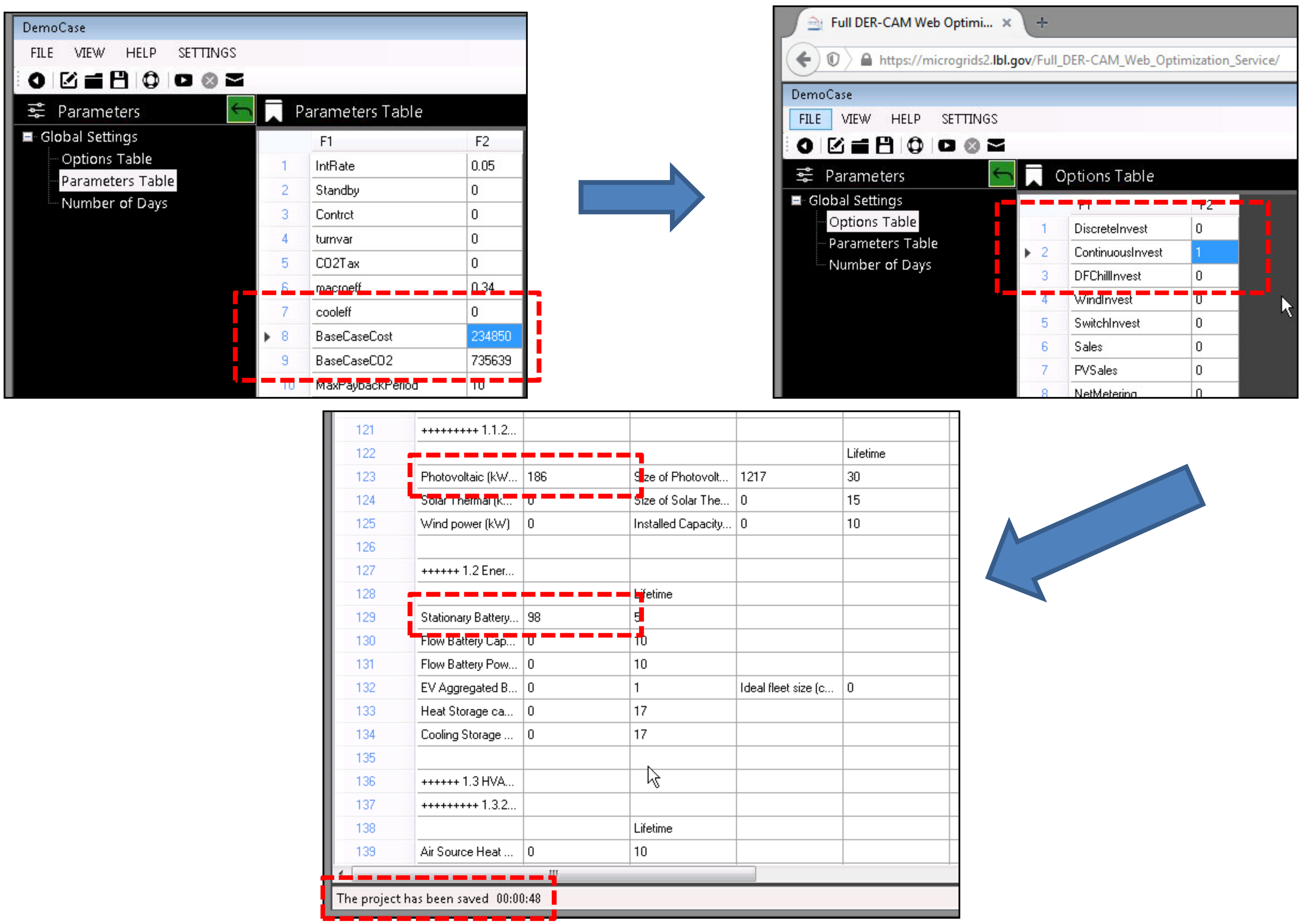
the total annual energy costs obtained in the reference case will then be used in the investment scenarios to allow estimating savings and return period of new investments



the results obtained in any run are stored on the server and can be sent via e-mail

Building a Model: Investment Case

after updating the reference costs and CO2 emissions, an investment case can be performed



Building a Model: Results

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ANALYTICS | PLANNING | OPERATIONS

Analysis: Economic and Environmental Impact, Savings, Annual Generation Mix

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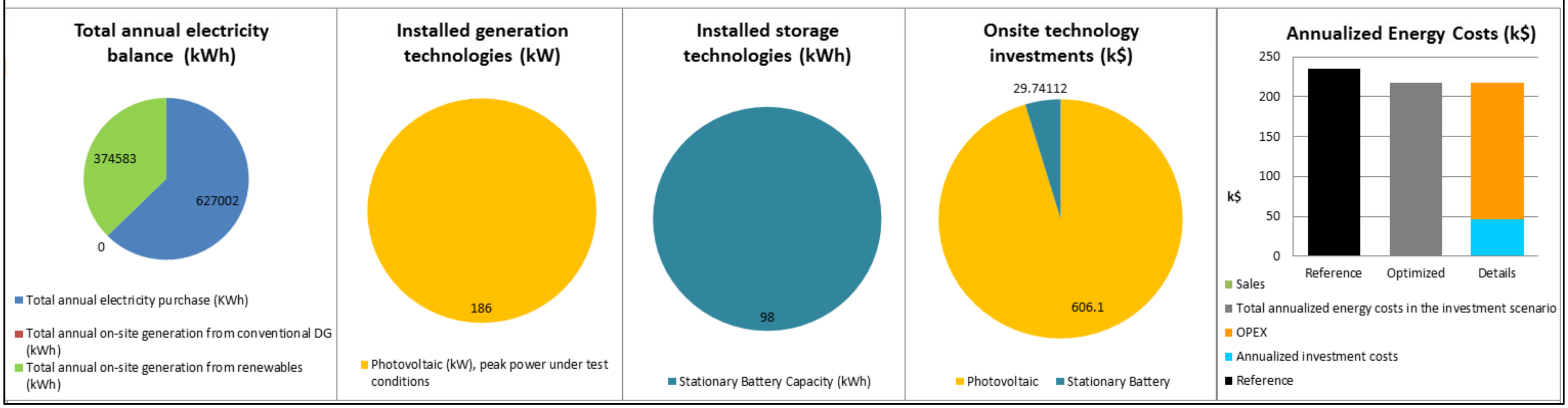
NOTE: Please enable MACROS in this workbook in order to process the DER-CAM result file
The macros will not work for Mac users: please use the Detailed Results tab and create your own graphs

	Total Annual Energy Costs (k$)
Reference	234.85
Investment scenario (incl. an	217.7
Total Savings (%)	7.3%
OPEX Savings (%)	26.9%

	otal Annual CO2 emissions (metric tons
Reference	735.6
Investment scenario (incl. anr	547.3
Savings (%)	26%

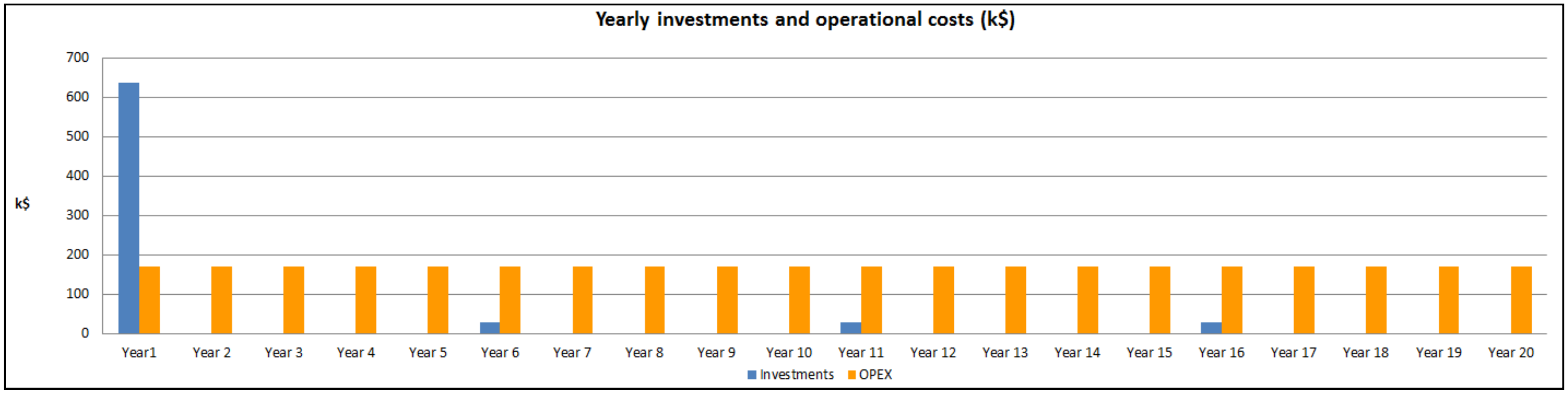
1metric ton=1.10 tons (US)

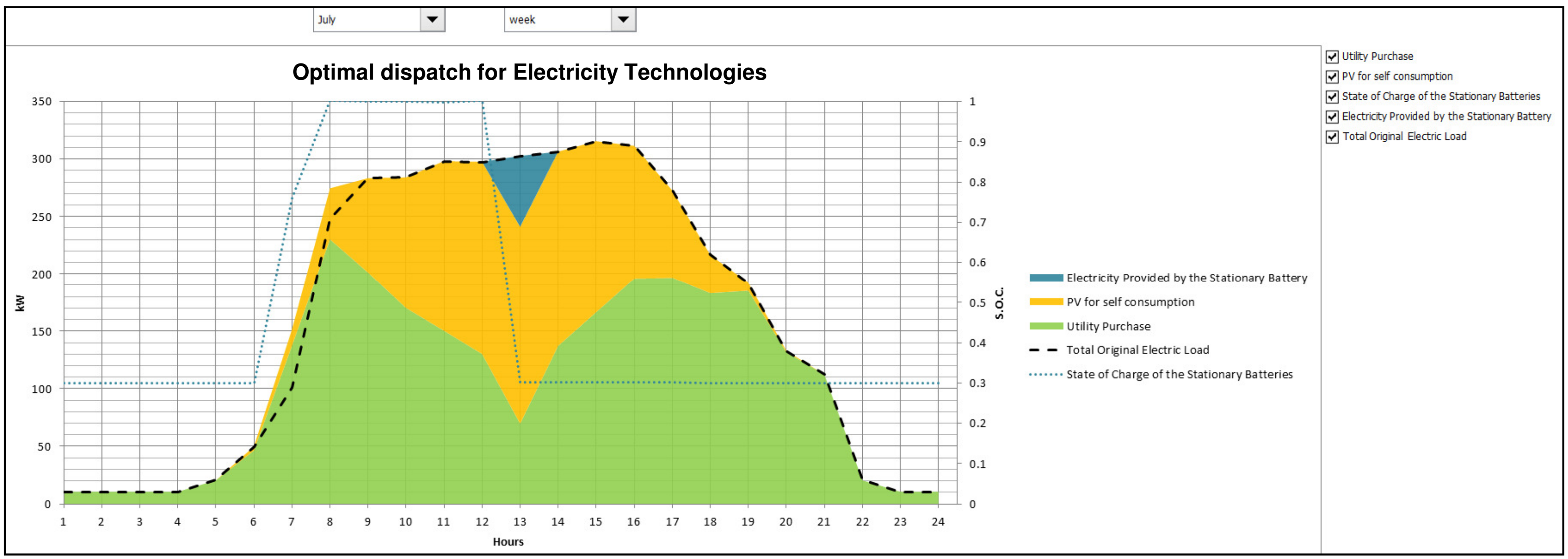


Building a Model: Results

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

Analysis: Yearly Investments and Costs, Optimal Generation Mix

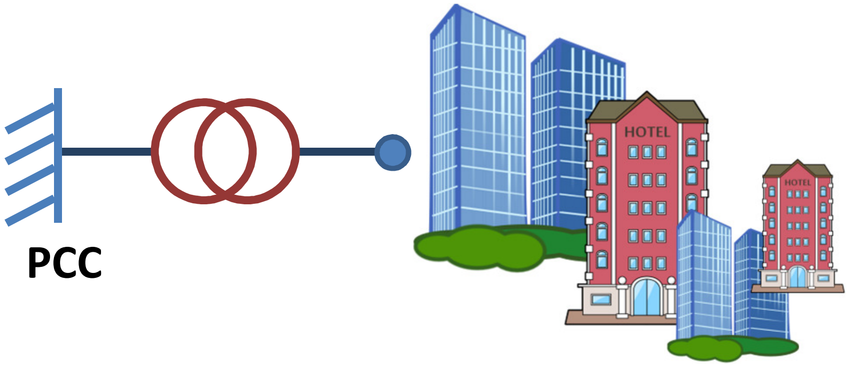




Excerpt of Technical Work Performed in 2nd quarter of FY15:

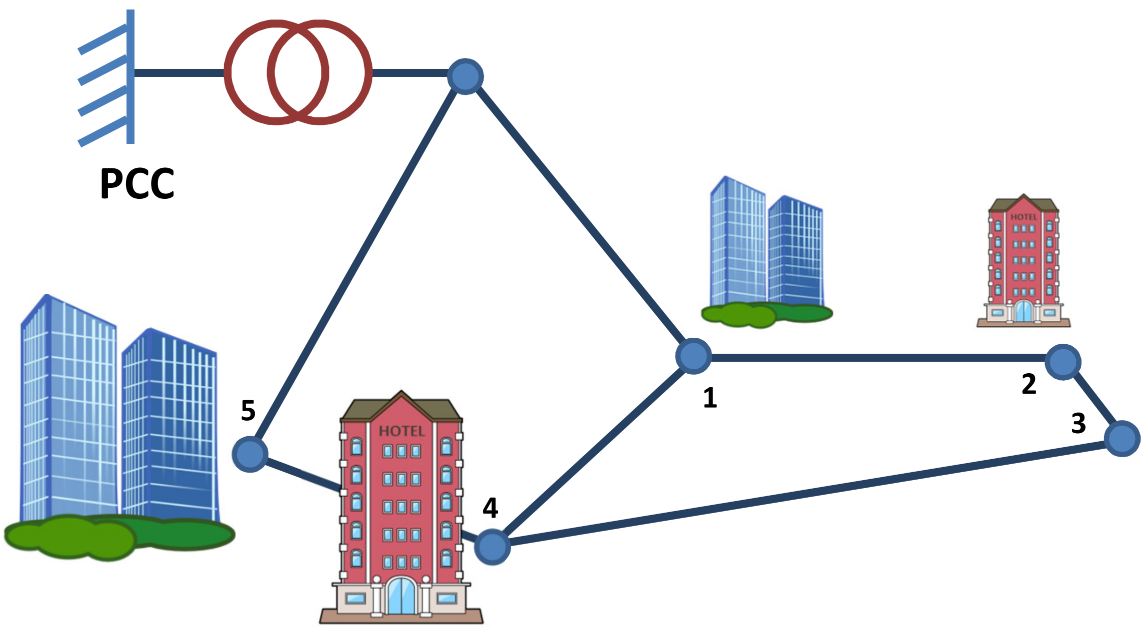
Microgrid Topology and Power Flow Analysis

Distributed (Multi-Location) vs. Single Site DER-CAM



Until now:

- **Input:** load for the entire campus or microgrid
- **Output:** optimal DER type and capacity for the entire campus



New:

- **Input:**
  - load profile for a full year for each location
  - electrical network configuration
- **Output:** optimal DER type and capacity for each location, *considering the network losses, and the network's voltage and current constraints*

Multi-Location DER-CAM Model Characteristics

- New:

  the Multi-Location DER-CAM returns the optimum DER portfolio for each bus, considering power flow constraints for each time step (not peak only)

  – electrical network configuration (cable impedances and ampacities) is an input

  – load profile for each location (bus) is an input

  – a linear distribution-level power flow model is integrated into DER-CAM, which considers:

    - cable R, X, and C
    - active and reactive power flow in the network
    - estimates losses in the network
    - imposes constraints on maximum bus voltage, minimum bus voltage, and maximum cable current

  – <u>fully functional</u>, but no Graphical User Interface (GUI) at this point

  – an interface for the new model is actually the hard part, but needed for wide-spread use

- Next Step:

  network configuration will also be a decision variable (determined by the optimization)

Power Flow Model in DER-CAM

$$Vr_m(t) = V_0 + \frac{1}{V_0}\sum\nolimits_{n\neq slack}\big(Zr_{m,n}(Pg_n(t) - Pl_n(t)) + Zi_{m,n}(Qg_n(t) - Ql_n(t))\big)$$

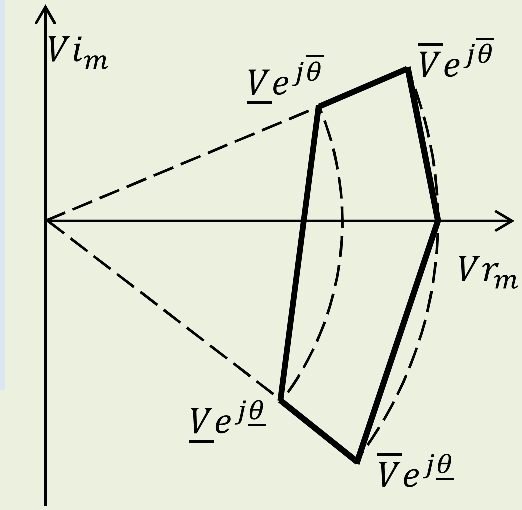
$$Vi_m(t) = \frac{1}{V_0}\sum\nolimits_{n\neq slack}\big(Zi_{m,n}(Pg_n(t) - Pl_n(t)) - Zr_{m,n}(Qg_n(t) - Ql_n(t))\big)$$

$$Ir_{m,n}(t) = Yr_{m,n}\big(Vr_n(t) - Vr_m(t)\big) - Yi_{m,n}\big(Vi_n(t) - Vi_m(t)\big)$$

$$Ii_{m,n}(t) = Yi_{m,n}\big(Vr_n(t) - Vr_m(t)\big) + Yr_{m,n}\big(Vi_n(t) - Vi_m(t)\big)$$

$$\sum\nolimits_m Pg_m(t) = \sum\nolimits_m Pl_m(t) + \sum\nolimits_m\sum\nolimits_n zr_{m,n} \times I^{sq}_{m,n}(t)$$

Power Flow Equations [1]



$$Vi_m(t) \leq \frac{\sin\overline{\theta} - \sin\underline{\theta}}{\cos\overline{\theta} - \cos\underline{\theta}}\big(Vr_m(t) - \underline{V}\cos\underline{\theta}\big) + \underline{V}\sin\underline{\theta}$$

$$Vi_m(t) \leq \frac{\sin\overline{\theta}}{\cos\overline{\theta} - 1}\big(Vr_m(t) - \overline{V}\big)$$

$$Vi_m(t) \leq \frac{-\sin\underline{\theta}}{\cos\underline{\theta} - 1}\big(Vr_m(t) - \overline{V}\big)$$

$$Vr_m(t)\tan\underline{\theta} \leq Vi_m(t) \leq Vr_m(t)\tan\overline{\theta}$$

Linearization of Voltage Constraints [2]

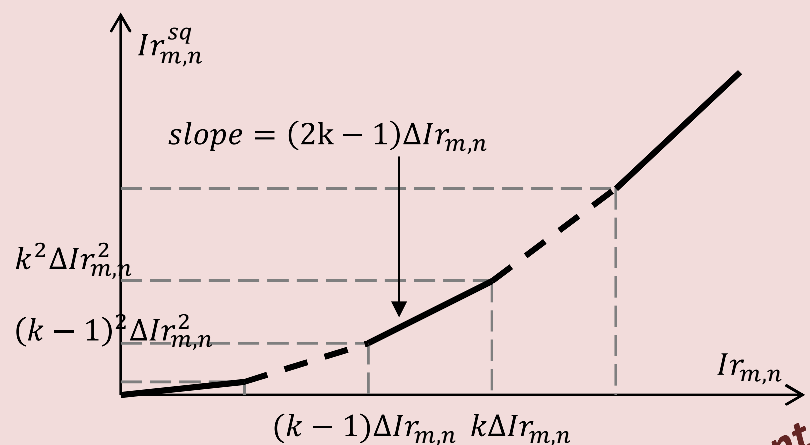
$$Ir^{+}_{m,n}(t) \geq \pm Ir_{m,n}(t), Ii^{+}_{m,n}(t) \geq \pm Ii_{m,n}(t)$$

$$Ir^{+}_{m,n}(t) = \sum\nolimits_k Ir_{m,n,k}(t), Ii^{+}_{m,n}(t) = \sum\nolimits_k Ii_{m,n,k}(t)$$

$$Ir_{m,n,k}(t) \leq \frac{1}{K}\times\overline{Ir}_{m,n}, Ii_{m,n,k}(t) \leq \frac{1}{K}\times\overline{Ii}_{m,n}$$

$$I^{sq}_{m,n}(t) = \sum\nolimits_k\left((2k-1)\left(\frac{\overline{Ir}_{m,n}}{K}\right)Ir_{m,n,k}(t)\right) + \sum\nolimits_k\left((2k-1)\left(\frac{\overline{Ii}_{m,n}}{K}\right)Ii_{m,n,k}(t)\right)$$

$$Ir^{sq}_{m,n}(t) + Ii^{sq}_{m,n}(t) \leq \overline{I}^{2}_{m,n}$$



Linearization of Current Constraints [2]

[1] Bolognani, S. and S. Zampieri, "*On the Existence and Linear Approximation of the Power Flow Solution in Power Distribution Networks,*" IEEE Transactions on Power Systems ,2015. PP(99): p. 1-10.
[2] Franco, J.F., et al., "*A mixed-integer LP model for the reconfiguration of radial electric distribution systems considering distributed generation,*" Electric Power Systems Research, 2013. 97(0): p. 51-60.

Case Studies: Comparison between Single Site and Multi-Location DER-CAM

- comparison of Single Site DER-CAM and Multi-Location DER-CAM
- assumptions for a micorgrid with four buildings:
  - small office, maximum electrical load 1,500 kW
  - small hotel, maximum electrical load 2,500 kW
  - large office, maximum electrical load 7,000 kW
  - large hotel, maximum electrical load 6,500 kW
- Case 1: Single Site DER-CAM: all loads combined
- Case 2: Distributed Multi-Location DER-CAM: electrical network is given and the loads are connected to different buses; a high ampacity (10 pu) for the cables
- Case 3: Distributed DER-CAM: electrical network is given and loads are connected to different buses; a low ampacity (3 pu) for the cables

Multi-Location DER-CAM Interface for Power Flow Models

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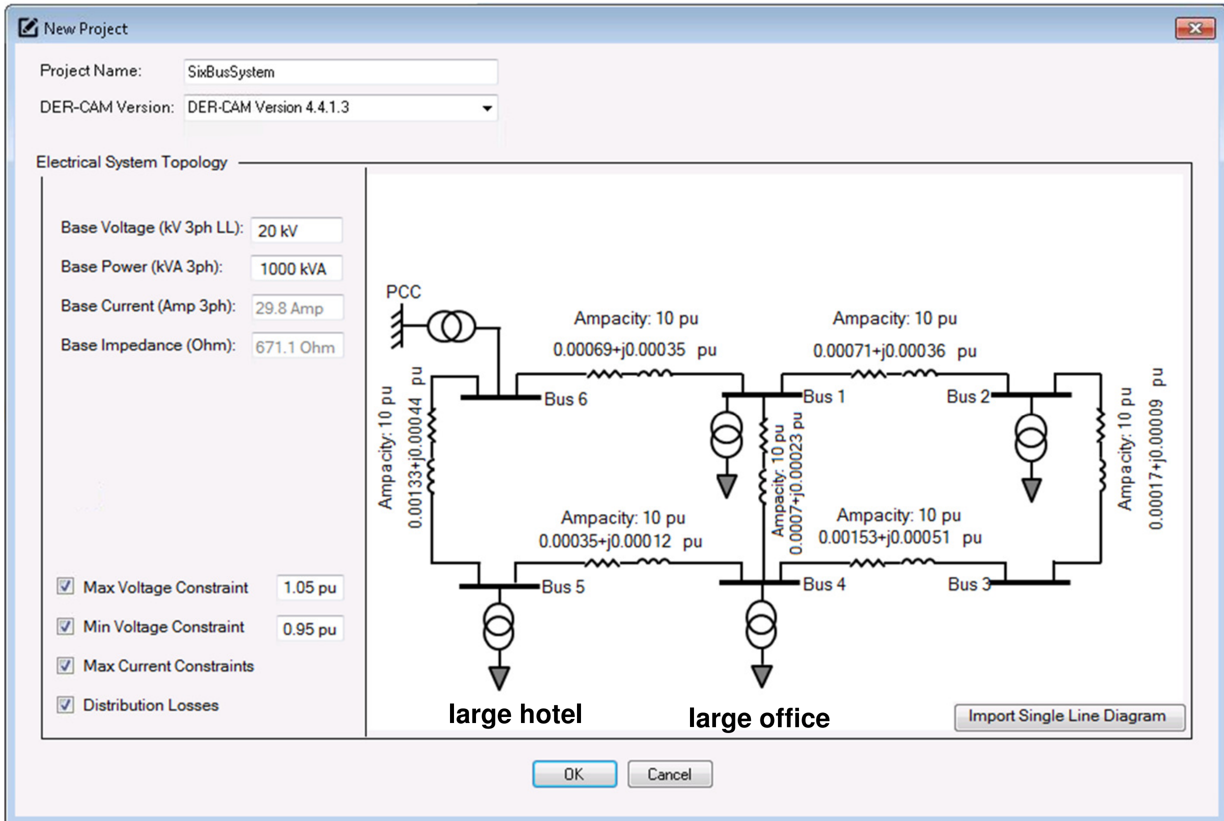

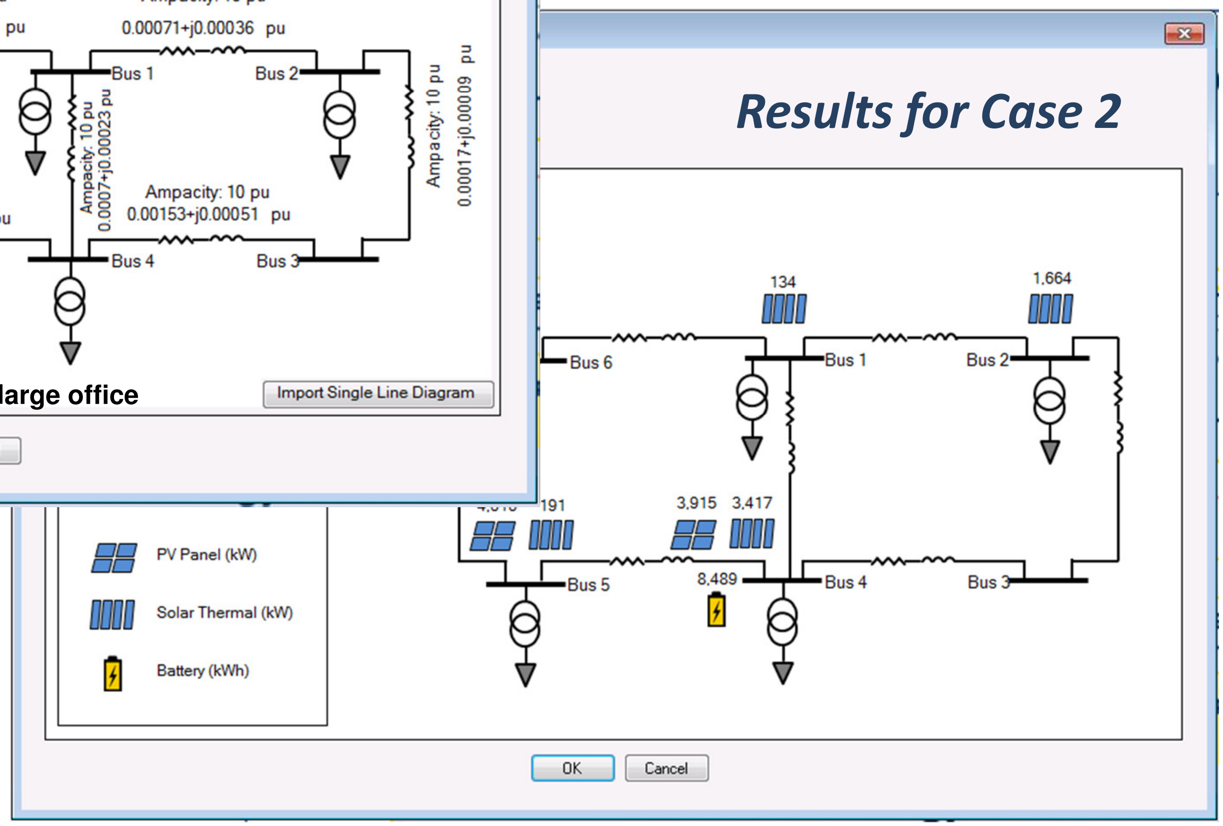

this is just an example on how it could be incorporated in the web version

Summary of the Case Studies

observation:

- the total capacities of each DER type in case 1 (Single Site DER-CAM) and case 2 (distributed with strong network) are very close
- however, the total capacity of each DER type in case 3 (distributed with weak network) is significantly different from cases 1 and 2

DER Type	Battery Capacity (kW)						Photovoltaic Capacity (kW)						Solar Thermal Capacity (kW)					
Location No	1	2	3	4	5	**Total**	1	2	3	4	5	**Total**	1	2	3	4	5	**Total**
Case 1	--	--	--	--	--	**7,217**	--	--	--	--	--	**7,172**	--	--	--	--	--	**5,590**
Case 2				8,489		**8,489**				3,915	4,010	**7,925**	134	1,664		3,417	191	**5,406**
Case 3	18,475	8,656	5,626	10,802	17,385	**60,944**	4,662	4,654	4,985	4,343	4,985	**23,628**	134	1,623		3,145		**4,901**

Next Steps

Next Steps

Outreach and TechTransfer

- continue on successful path for wide acceptance by communities and engineering firms
- training tools for users, workshops, tutorial movies on specific microgrid case problems
- detailed microgrid design for Fort Hunter Liggett

Technical work

- Microgrid power flow verification with modelling tools such as GridLab-D
- Graphical User Interface for power flow version
- DC power flow?
- networked microgrid optimization (together with ANL)
- enable DER-CAM with unbundled transmission and distribution tariffs for changed tariff structures for advanced microgrids, “adapting to the changing regulatory environments”

Questions and comments are very welcome!